DOCUMENT RESUME

ED 129 606 SE 021 403

AUTHOR	Dukert, Joseph M.
TITLE	Atoms on the Move: Transporting Nuclear Material.
INSTITUTION	Energy Research and Development Administration, Oak Ridge, Tenn.
PUB DATE	75
NOTE	62p.; Photographs may not reproduce well
EDRS PRICE	MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS	*Instructional Materials; *Nuclear Physics; Physics; *Safety; *Transportation
IDENTIFIERS	*Energy Research and Development Administration; ERDA

ABSTRACT

This is an Energy Research and Development Administration pamphlet outlining in detail the many aspects involved in safe transportation of all types of nuclear materials. The detailed safety regulations and designs of various shipping packages and containers are emphasized. Included are maps of waste burial sites and fuel production facilities, an appendix on federal nuclear packaging restrictions, and a bibliography of government documents and films relating to transportation of nuclear materials. (SL)

****
* Documents acquired by ERIC include many informal unpublished *
* materials not available from other sources. ERIC makes every effort *
* to obtain the best copy available. Nevertheless, items of marginal *
* reproducibility are often encountered and this affects the quality *
* of the microfiche and hardcopy reproductions ERIC makes available *
* via the ERIC Document Reproduction Service (EDRS). EDRS is not *
* responsible for the quality of the original document. Reproductions *
* supplied by EDRS are the best that can be made from the original. *
****

ATOMS ON THE MOVE

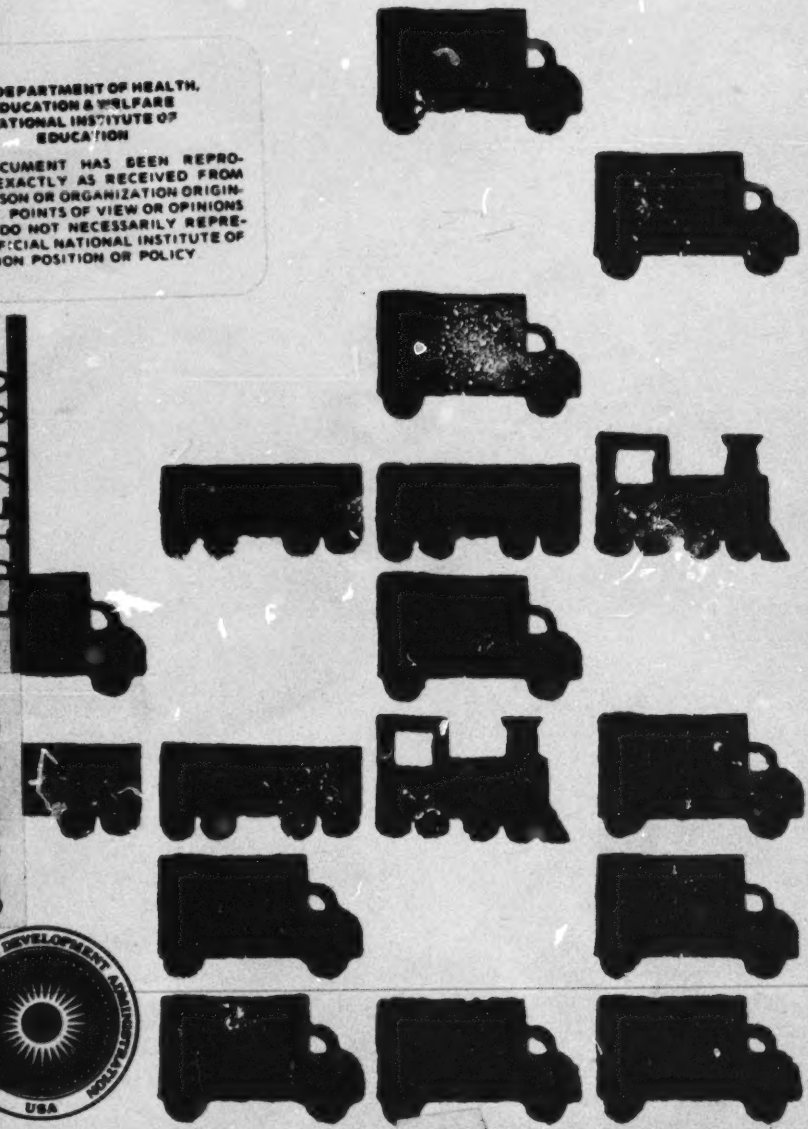
Transporting Nuclear Material

by Joseph M. Dukert

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

ED129606
SE 021 403



ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
USA

The Energy Research and Development Administration publishes a series of booklets for the general public. Please write to the following address for a title list or for information on a specific subject:

USERDA—Technical Information Center
P. O. Box 62
Oak Ridge, Tennessee 37830

Joseph M. Dukert is an author and consultant who received his B. A. degree in journalism from the University of Notre Dame in 1951 and completed graduate studies in international relations both in this country and in Europe.

As Public Relations Director for the Nuclear Division of the Martin Marietta Corporation and later for that company's Research Institute he developed programs that interpreted both technology and basic research in physics, mathematics, metallurgy, and the biosciences to a diverse group of audiences, including the general public.

He has produced several movies, one of which received a "Cindy" as the best industrial sales film of the year. Another of his films was chosen as the outstanding television newsreel film of the year at the Rome Film Festival.

He is the author of several popular science books, including *Atompower* (Coward-McCann, 1962), *This is Antarctica* (Coward-McCann, 1965 and 1972), *Nuclear Ships of the World* (Coward-McCann, 1973), and numerous booklets, magazine and newspaper articles, and movie and TV scripts.

ATOMS ON THE MOVE

Transporting Nuclear Material

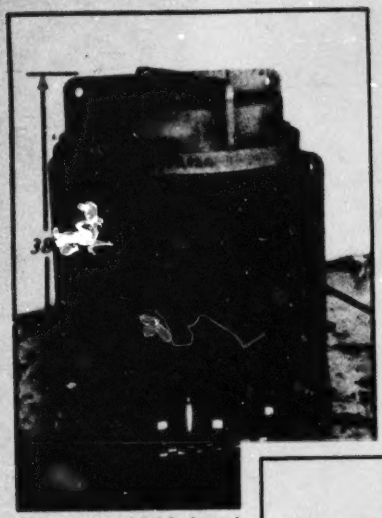
by Joseph M. Dukert

Contents

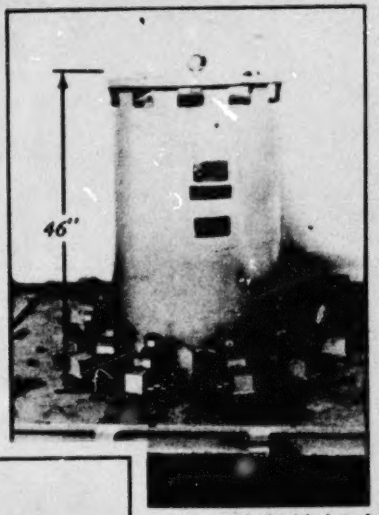
How Do We Get From Here to There? 1
Some Essential Definitions 3
Transportation in the Nuclear Fuel Cycle 5
Transportation for Medicine, Industry, and Research . . 17
Transportation Rules: Who? What? Why? How? 25
How Safe Is "Safe"? 33
Accidents *Do* Happen 38
Are We Ready for Tomorrow? 45
Appendix I—Packaging Restrictions for Some Common Radioactive Substances 50
Appendix II—Measuring Radiation 51
Bibliography 54
Motion Pictures 55

Energy Research and Development Administration
Office of Public Affairs
Washington, D.C. 20545

Library of Congress Catalog Card Number: 75-600048
1975

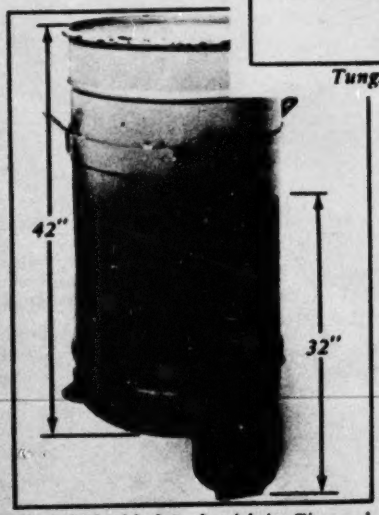


Uranium-Shielded Cask

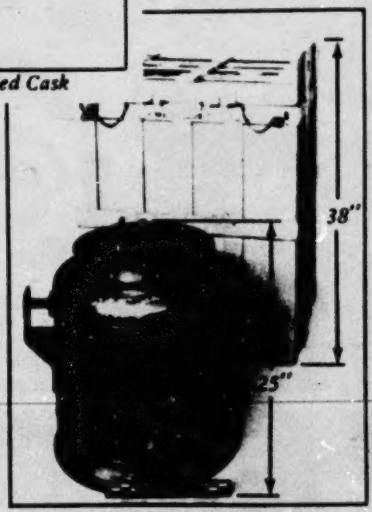


Double-Lead-Shielded Cask

Tungsten-Shielded Cask



Lead-Shielded Cask with its Fire and Impact Shield



Radioactive Gas Cylinder with its Framed-Plastic Fire and Impact Shield

How Do We Get From Here to There?

Would it be safe and sensible to ship nuclear materials from one city to another in a cardboard box? It *might* be. On the other hand, you *might* need a multi-ton portable vault bolted securely to its own flatbed truck or railroad car. In some cases the law (and good sense) might even require you to use a specially designed armored car with armed guards.

The term "nuclear material" includes an enormous variety of items; for example, an implantable pacemaker for a cardiac patient's heart; a bottle of liquid for "tracer" studies in a high school classroom; uranium ore, which is "feed material" for reactor fuel; or nuclear wastes, which emit radiation ranging from very high levels to those that are virtually undetectable. About a million shipments of nuclear material take place each year in this country alone. They move by land, sea, and air in hundreds of different types of approved containers.

Like many other materials in commerce, radioactive substances are potentially hazardous. The degree of possible danger dictates the way in which the regulations of the U. S. Nuclear Regulatory Commission (NRC) and the U. S. Department of Transportation (DOT) require that specific types of shipments be handled. But, quite properly, *all* nuclear shipments are labeled "radioactive", and this is a "scare word" to the general public—especially if there are transportation accidents.

Figure 1 These shipping containers have been developed to meet the new safety standards of the U. S. Department of Transportation for the packaging of large quantities of radioactive materials.

Of course there *have* been shipping accidents involving nuclear materials but their radioactivity has not injured anyone. More accidents will undoubtedly occur. So, even though the safety record in nuclear transport is far more reassuring than that for other hazardous materials (such as explosives, chlorine, flammable liquids, corrosives, etc.), a good way to keep up public pressure for *maintaining* adequate precautions is to make people more aware of what is involved—without either minimizing or exaggerating the facts. Although careful analyses show that the likelihood of a *catastrophe* involving nuclear shipments is practically zero, broader understanding of basic principles might easily help to avert injuries, property damage, and even fatalities by using common sense in cases where *some* exposure to radiation *does* take place.

Some Essential Definitions

You transport nuclear material whenever you move. This is because there are millions of radioactive atoms in the body of every human being, and this was true even in prehistoric times.

This doesn't mean that all nuclear materials can be treated as casually as the small amounts we normally carry around inside us. Nor should it suggest that the sources of radioactivity on earth have stayed constant for millions of years. Since learning to produce and use nuclear energy, man has begun to *concentrate* nuclear materials for various reasons, and also to produce "artificial" radioactivity in many new chemical and physical forms. So the rules for safe transportation are complex.

Different types of radioactive atoms (called radionuclides) emit different kinds of radiation.* Some of these emissions are more difficult to block by means of shielding than others. Radionuclides also vary in their chemical characteristics; for instance, radioactive iron does not act and react chemically in the same way that radioactive oxygen does. Furthermore, the likelihood that a radioactive substance could be spread around in the atmosphere or absorbed by the human body in the event of its release depends to a large extent on its physical form and physical properties. Without going into detail, it should be clear that a fine powder or a vapor or a liquid will follow a different course than might be expected for a solid insoluble chunk.

All these factors—and more—are considered in setting standards of safety for the movement of radioactive materials. Some of the factors played a fairly obvious role in establishing the packaging restrictions shown in Appendix I on page 50. But such ground rules don't make much sense (and certainly can't be put into effect) unless a few basic terms are defined first. Without some accepted units for

*The varieties of nuclear radiation are discussed in many of the other booklets in this series, but perhaps nowhere more comprehensively than in the one entitled *Your Body and Radiation.*

measuring radiation and radioactivity, there would be no practical way of differentiating between the radiation effects of a luminous watch dial and those of a potentially lethal slug of strontium-90. So, before going any further, it's essential to mention at least three fundamental terms of measurement: curie, roentgen, and rem. For those who are interested, Appendix II on pages 51–53 explains these terms in more detail. It also defines the much smaller quantities of each that are used more often in discussing most nuclear shipments—namely, *milli*curie, *milli*roentgen, and *milli*rem.

Nuclear radiation is similar in many respects to more commonly accepted forms of radiation, like that which reaches us from the sun. Using this analogy, a curie is the unit that identifies the strength of the source—rather like measuring the size and temperature and basic radiation output of the sun *at its surface.* A roentgen is similar to a measurement of how much solar radiation reaches a single person on earth (whether this total is absorbed in a short time or a longer period, in partial shade or in bright sunlight). A rem tells how much actual "sunburn" the person gets.

As a further note of background, it might be wise to point out that the three basic terms are often used in combination with other references to measurement, and this pinpoints their meaning and increases their helpfulness in describing a situation or laying out guidelines in regard to transportation:

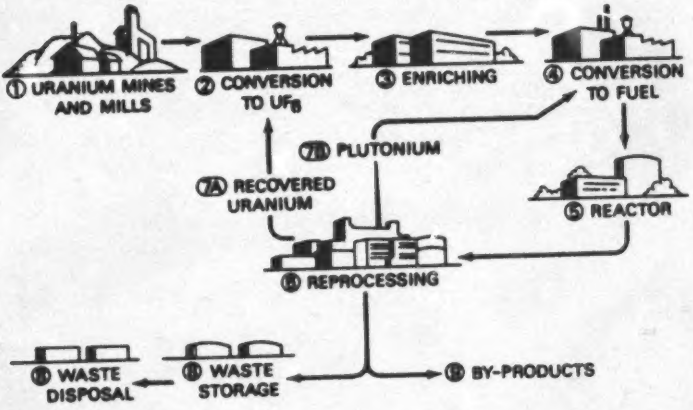
- The radioactive concentration of a solution may be described in terms of so many millicuries *per liter.*
- The acceptable radiation reading from a certain type of package might be expressed as so many millirems *per hour* (mrem/hr).
- The cumulative radiation dose, which is allowed for a transportation worker, such as a truck driver, is normally expressed as a certain number of millirems *per month* or *per year.*

With these basics in mind, it should be a lot easier to explain and understand the complex business of transporting radioactive materials, whatever they may be.

Transportation in the Nuclear Fuel Cycle

Even though only a tiny percentage of the annual shipments of radioactive material is associated with the generation of electricity in nuclear power reactors, this aspect of transportation draws an inordinate amount of public attention; and the subject has so many nuances in itself that it deserves to be treated separately. Before it was supplanted in 1975 by the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC), the U. S. Atomic Energy Commission published two long summaries of the safety aspects of these shipments,* but these documents are jammed with statistical data and charts that might overwhelm an unprepared reader. So here is a capsule view of the nuclear fuel cycle with emphasis on the movements of radioactive materials among the various sites involved:

REPROCESSING IN THE NUCLEAR FUEL CYCLE



Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants and *Environmental Survey of the Uranium Fuel Cycle.* (See the bibliography that begins on page 54.)

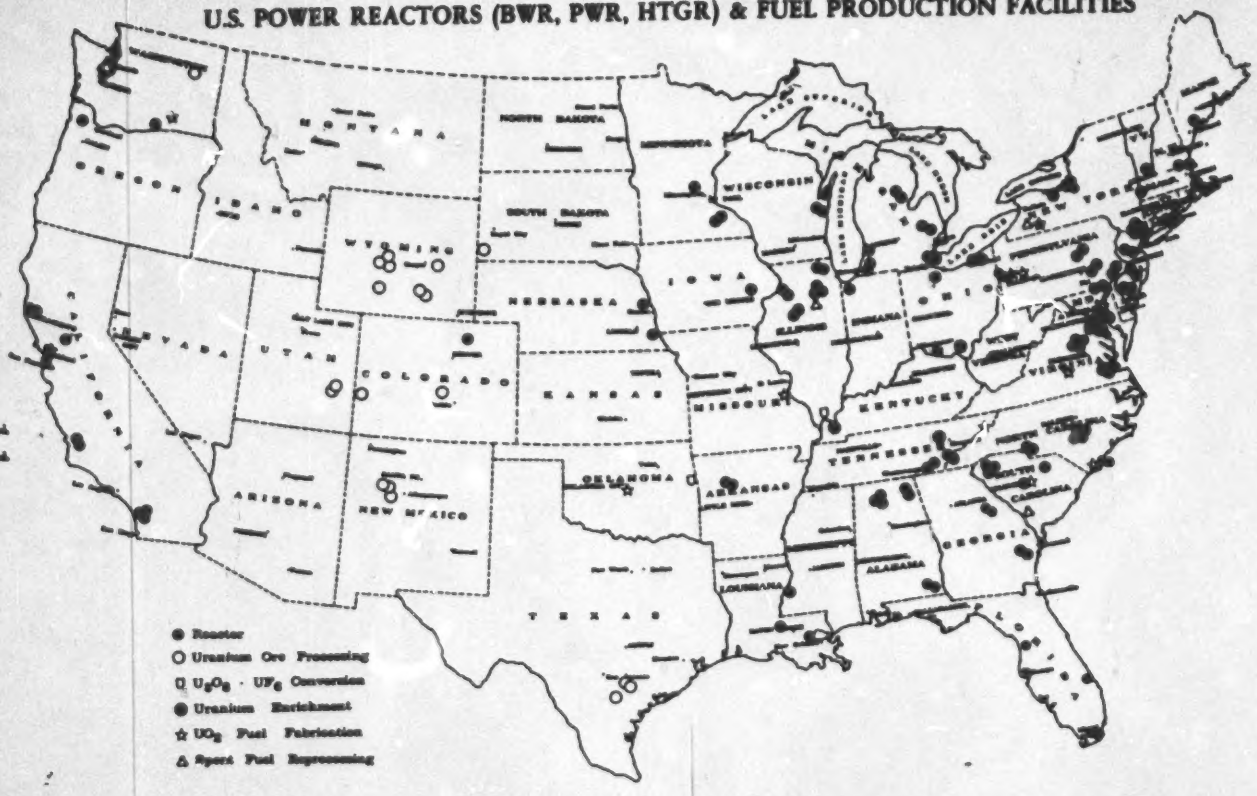

U.S. POWER REACTORS (BWR, PWR, HTGR) & FUEL PRODUCTION FACILITIES
MONTANA
NORTH DAKOTA
MINNESOTA
OREGON
IDAHO
WISCONSIN
MICHIGAN
SOUTH DAKOTA
WYOMING
IOWA
NEBRASKA
NEVADA
UTAH
COLORADO
KANSAS
MISSOURI
KENTUCKY
TENNESSEE
OKLAHOMA
ARKANSAS
ARIZONA
NEW MEXICO
SOUTH CAROLINA
GEORGIA
ALABAMA
LOUISIANA
TEXAS
Reactor
Uranium Ore Processing
$U_3O_8 \cdot UF_6$ Conversion
Uranium Enrichment
UO_2 Fuel Fabrication
Spent Fuel Reprocessing

Figure 2

Uranium is only mildly radioactive in its natural state as it comes from the mine (1). In fact, much of the radioactivity in the ore may come from elements other than uranium, such as radium and radon. And most of those impurities are removed during milling and the initial purification steps, which usually take place at or near the mine site. The second step (2) in the cycle is to further purify the uranium compound (an oxide) and to convert it into uranium hexafluoride (UF_6), which vaporizes at a low temperature and is "enriched" via the gaseous diffusion process (3). During the enrichment process, UF_6 gas is piped through miles of filters inside a huge plant so that the slightly heavier atoms of a uranium form called uranium-238 can gradually be reduced in proportion to the much rarer (and more valuable) atoms of uranium-235. If the uranium were destined for use in a nuclear explosive device or in a compact military reactor for shipboard use, the percentage of uranium-235 would have to be increased by enrichment from less than 1% to more than 90%.* For most commercial power reactors, however, enrichment is only to a few percent uranium-235. (One exception is mentioned on page 14.) This is important when one considers the problem of safeguarding nuclear materials during transportation against theft or diversion for illegal nonpeaceful uses.

The most common form of power reactor fuel used in the U. S. consists of small cylindrical pellets of a uranium ceramic compound, loaded end to end into long metal tubes. The tubes, in turn, are bundled together into "fuel assemblies" (4). Before it is used in a reactor, such an assembly is not highly radioactive and can be handled quite safely. Transportation involves a few complications (see pages 15 and 16, as well as Fig. 4), but radiation is not a problem.

*Transportation of various forms of radioactive material for military purposes will not be treated in this booklet at all because of classification regulations. Needless to say, many thousands of such shipments have taken place safely, albeit secretly. Nuclear explosives are transported under heavy guard, and the most elaborate precautions are taken at the crucial steps associated with their production.

Figure 3 Chunks of uranium ore can be handled in one's bare hands without a radiation hazard.

As the reactor operates, however, the fuel undergoes a nuclear transformation (5). Its physical appearance remains practically unchanged, but its radioactivity is multiplied perhaps a million times, which makes the fuel very hot. The ceramic pellets inside the tubes become a composite of uranium, a totally new material called plutonium, and a great variety of fission products that result from the splitting (fissioning) of atomic nuclei during the nuclear chain reaction to produce heat within the reactor. Before it can be shipped to the reprocessing plant (6) for the next step in the fuel cycle, the "spent fuel" is allowed to cool off for at least several months in a storage pool at the generating site. Its radioactivity declines appreciably as radioisotopes with short half-lives "decay", but millions of curies are still involved. Because radioactivity generates heat, the water in the pool provides necessary cooling as well as radiation shielding. When the bundles are ready for shipment, they must be transferred under water to massive, heavily shielded and cooled portable vaults, called "casks", which are the most carefully designed shipping containers in human history (see Figure 5).

When the spent fuel reaches the reprocessing plant, the pellets are removed from their metal cladding by remote-control equipment operating inside "hot cells" built of concrete many feet thick. Using fairly conventional chemical steps from that point on, the contents of the fuel pellets are separated at the reprocessing plant into their various major constituents, and each of these may move on in a different direction as the diagram on page 5 also shows:

- The unused *uranium* recovered from spent fuel can reenter the fuel cycle (7A), but first it must undergo additional enrichment because most of its uranium-235 was used (i.e., fissioned) during its stay in the reactor. Reprocessed uranium is a little more radioactive than natural uranium, because it contains larger amounts of another, more active isotope (uranium-234), but generally the same transportation rules apply to both.

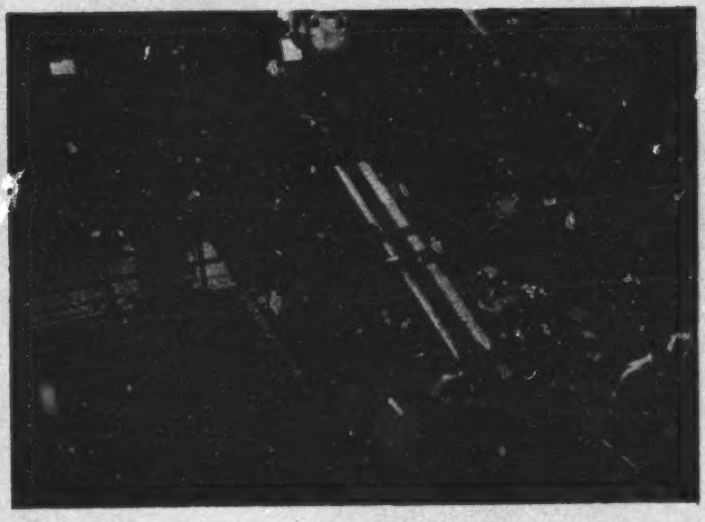


***Figure 4** Only one or two fresh bundles of reactor fuel are normally shipped in each container. Typically, a bundle rests on a "strongback", which is shock-mounted to the outer shell and protects the relatively fragile fuel.*

- Purified *plutonium* (7B) is sufficiently fissile* already, so it is ready at once to go to a fuel manufacturing plant. For a number of reasons, however, its transportation is governed by its own unique set of rules, which are discussed on page 13.
- Reprocessing facilities normally are associated with approved burial sites, so that nuclear waste of *low* radioactivity levels can be disposed of locally without further transportation.† *High*-level waste, on the other hand, must be removed from the site eventually. Under existing regulations, the reprocessor is given a limited time within which to convert all high-level liquid wastes to a stable solid form (8); and the solids must later be shipped to a central Federal Repository. Although no such shipments of high-level waste have yet taken place, the casks used will undoubtedly be very similar to those used now for "spent fuel" because radiation and handling aspects will be about the same.‡
- Some nuclear materials that are now treated as waste may someday be valuable enough in themselves to justify separating them as by-products of the reprocessing operation (9). Their shipments to users in medicine and industry will be regulated in the same way as other radionuclides discussed in the next section, however, because at that point they will actually have *left* the "fuel cycle".

Throughout the nuclear fuel cycle, appropriate transportation techniques have been developed to forestall

---

*Fissile is the technical term designating materials whose atomic nuclei are *readily* fissionable. Almost *any* nucleus can be fissioned under *some* conditions.

†Wastes that contain significant amounts of plutonium or some other highly toxic, long-lived "artificial" elements, however, have to be handled separately—even if their "alpha" type radiation requires only slight shielding. Future regulations may require that, like high-level waste, they be shipped to a Federal Repository.

‡Plans, prospects, and principles regarding this part of the fuel cycle are covered in considerable detail in a question-and-answer booklet entitled *Everything You Always Wanted to Know About Shipping High-Level Nuclear Wastes* (WASH-1264) that is listed in the bibliography on page 54.

Figure 5 A spent fuel element enclosed in a cask is lowered into an unloading pool. The fuel element is then removed under water and transferred to an adjoining storage pool.

potential problems in four areas: radiation effects, decay heat, accidental nuclear chain reactions (criticality), and theft of nuclear materials for illegal nonpeaceful purposes. The extent of the radiation factor, as we have seen, depends on the phase of the fuel cycle that we are discussing. In any event, radiation effects can be reduced to an acceptable level by a combination of shielding, separation distance, and limits on the time of exposure. Those details are treated in the section that begins on page 25. *Heat* is another possible problem that can be eliminated by rather simple design methods: When radioactive materials are shipped in such quantities that they generate high temperatures within themselves, the shipping containers either have built-in mechanical cooling systems or protruding "fins" to radiate the heat away. Sometimes both are used. The other two problems—criticality and theft—are both based on the simple fact that fissile material can release energy quite violently under certain conditions. So the steps taken to

prevent that from happening as an outgrowth of transportation within the fuel cycle simply add up to *preventing those circumstances from arising.*

An energy-multiplying "chain reaction" is *not* easy to produce. If it were, nuclear energy might have been discovered centuries earlier. The "chain" is made possible by the fact that neutrons can cause certain atoms (like uranium-235) to fission, *and* that the fission process itself releases more neutrons. But the catch is that those fresh neutrons can just as easily leak away from the fissionable material *or* be absorbed in something without producing additional fissions to keep the reaction going. To produce a chain reaction, a certain minimum amount of fissile material, called a critical mass, is necessary. It must *also* be arranged so that enough of the neutrons, which fly off in all directions, will stay within a reasonably compact volume, which is called the critical geometry.

Shipping regulations for potentially fissionable material are drawn up with these facts in mind. For example, it may be required that the material be suspended by a "birdcage" framework within its shipping container (see Figure 6) so that no combination of such containers could ever produce a critical mass and critical geometry accidentally.*

As for the final major problem area—the danger of diverting nuclear materials—it is helpful to review the stages of the fuel cycle once more: Until uranium has been *enriched,* it obviously would be of no value to someone who was trying to build a "bootleg" bomb. In fact, the fuel compounds used for the great bulk of commercial power reactors *never* reach an enrichment that could be used to produce an explosion, even in completed fuel. Once

*Another fact about fission that has to be kept in mind is that the possibility of a chain reaction within any mass, which is not *pure* fissile material, can be enhanced by the added presence of a substance called a "moderator". The physical reasons for this aren't essential here; the important thing to note is that ordinary *water* is a good moderator. Therefore, the rules for transporting anything that contains readily fissionable material must take into account that immersion in water is a fairly common shipping accident.

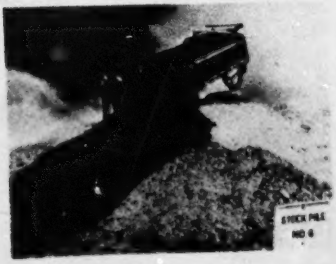
Figure 6 A "birdcage" shipping container.

plutonium has been built up within the fuel bundles (by use in the reactor), there *is* some pure fissionable material that could be separated through chemical means. But by that time the fuel bundles are intensely radioactive; a hijacker who tried to intercept them on the way to a reprocessing plant would face enormous difficulties in handling them and would still need elaborate *shielded* processing equipment at his hideaway to extract the plutonium.

The only part of the fuel cycle in which plutonium *might* become accessible to unauthorized persons is after it has been separated and purified at the reprocessing plant and before it is recycled into another reactor as a component of fresh fuel. For that reason, this is where extra security precautions are added to the other transportation regulations. Armed guards accompany each shipment of significant amounts of this fissile material. Special armored vehicles are also being developed to thwart potential hijackers by using a variety of "James Bond" techniques, such as constant radio contact with authorities, time locks, self-immobilization, etc.

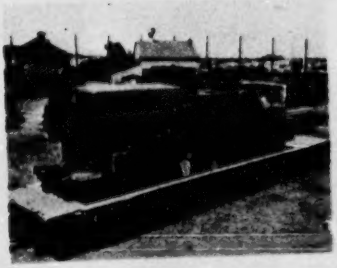
At present the amount of plutonium in the commercial fuel cycle is still relatively small. It was estimated that only about 1000 pounds (500 kilograms) were available for recovery nationwide as late as 1973. But the estimate for 1980 is approximately 10 tons; and transport regulations are

Figure 7 Transportation at various stages of the fuel cycle.

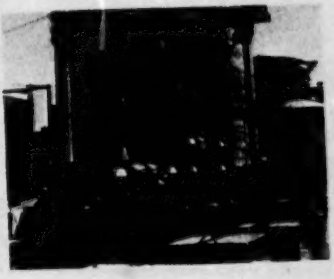


A. Uranium ore.

B. Uranium oxide.



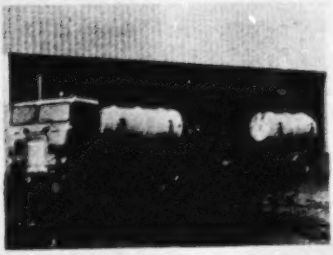
E . Fresh reactor fuel.



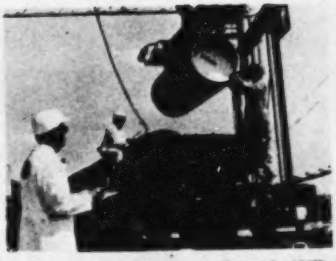
F. Spent fuel.

being tightened accordingly because of plutonium's potential hazard as a biological poison. In mid-1975, the Nuclear Regulatory Commission ordered its licensees to suspend all air shipments of plutonium except for that contained in individual medical devices like pacemakers. Furthermore, starting in 1977, whenever more than 20 curies of any isotope of plutonium are shipped from one place to another, the material will have to be in solid form and inside a double layer of containment. A solid, of course, is much less likely to be dispersed into the air even if it was outside of its container. Furthermore, most plutonium solids tend to form large, insoluble molecules (polymers) when they come in contact with water.

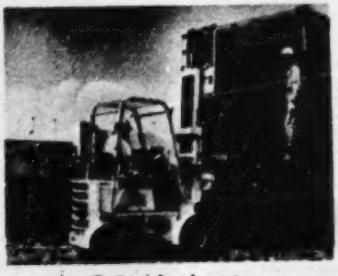
As for uranium, the High-Temperature Gas-Cooled Reactor (HTGR) is one exception to the general rule that commercial reactors use only *low*-enriched material. Fresh



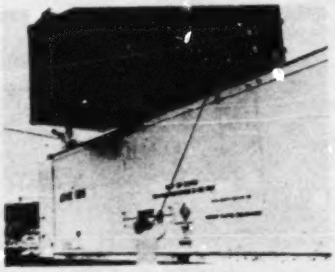
C. Natural uranium hexafluoride (UF_6).



D. Enriched uranium hexafluoride (UF_6).



G. Low-level waste.



H. Low-level plutonium wastes.

fuel for the HTGR *does* contain highly enriched uranium carbide mixed with graphite, so extra security precautions apply to its delivery and handling. Only two HTGR's are operating in the U. S. at present, however, and reprocessing of their fuel is expected to be done only in Government facilities until well into the 1980s.

The great variety of shipping containers and methods used at various stages of the nuclear fuel cycle is illustrated by the series of pictures above. Uranium ore is not hazardous and may move in open trucks or rail cars. Even after the concentrating and milling operations, uranium may still be shipped in ordinary drums. Uranium hexafluoride still has very low levels of radiation, but it must be kept tightly sealed because it is chemically corrosive. Furthermore, UF_6 is handled with additional care after *enrichment* because of its greatly increased monetary value. From that point on it also

must be shipped in some sort of "birdcage" arrangement to prevent accidental criticality.

Completed fuel assemblies are even *more* valuable—worth perhaps $100,000 apiece. They are quite heavy, but fairly fragile; and they could not be used in a reactor if they were damaged in transit. Normally only one or two bundles will be loaded into each of the shipping containers shown in the pictures and the number of containers on the trailer is limited. But radiation is low, and there need be little concern about release of radioactivity.

In the case of *spent* fuel shipments, of course, the radioactivity is much higher. The rail or truck casks used must be designed to survive even a total wreck, violent blaze, or explosion without releasing their contents in any way that could cause widespread damage or casualties. Similar criteria will apply to high-level waste shipments when they begin, and, like spent fuel containers, those casks will have to provide some means of dissipating heat from their contents during transit. Finally, any readily fissionable material in the fuel cycle (highly enriched uranium or purified plutonium) must be safeguarded to prevent theft as well as accidental criticality.

Before a construction permit or operating license is granted for any type of nuclear power installation, the possible adverse effects of related transportation must be presented and analyzed. Both the safety factors and environmental effects are considered, and a go-ahead is given only if any such impacts are judged to be acceptably small.

Transportation for Medicine, Industry, and Research

Less than 1% of nuclear material shipments that take place today move to or from nuclear power plants, or elsewhere in the nuclear fuel cycle. Almost all the rest—many hundreds of thousands each year—are associated with the ever-expanding use of radioisotopes in medicine, industry, and a broad range of scientific investigations.

Some 5000 U. S. hospitals now use radioisotopes in some manner or other, and about half of those have facilities for the officially recognized specialty of nuclear medicine. It is estimated that one American in four who is admitted to a hospital these days will receive some diagnosis that involves radioactive "tracers". The therapeutic use of massive radiation sources in treating various forms of cancer is also well known. Medical radioisotopes are used many thousands of times each day in all parts of the country, so radiopharmaceuticals and other radioactive materials that help to preserve public health must reach their destinations by some means of transportation.

The use of tracers depends on the fact that radioactive atoms of any element react in the same way biochemically as stable atoms of that element, but their position in the body can be *detected* by radiation monitors or radiography as these atoms decay and emit radiation. To reach the thyroid, then, a doctor has his patient swallow a solution containing a radioactive form of *iodine*. Radio*phosphorus*, on the other hand, tends to concentrate in certain types of tumors. And radio*iron* goes into red blood cells. The point is that *many different* radionuclides must be used for nuclear medicine to achieve its full potential. Some can be shipped in solid compounds, but others must be in liquid form. The ones that decay quickly because of their radioactivity must often be delivered to hospitals by air.

Obviously, tracers are selected in part so as to minimize the adverse effects of radiation on the patients. Other considerations are: the *type* of radiation they emit; the

radioactive half-life, which is the time it takes for half of a sample's atoms to lose their initial radioactivity; and the biological half-life, which is a measure of the time a substance may be expected to remain in the human body before being eliminated by natural processes. But a careful choice of these characteristics also tends to limit the potential dangers of a material if it should be released inadvertently on its way to the hospital or clinic. So the fact is that most of the packages containing medical tracer material, which move about the country, are *not* especially hazardous. After all, if a doctor is going to inject them into a patient, how hazardous *can* they be?

In the case of radiation sources that are used to destroy cancer cells, the situation may be somewhat different. The quantities of radioactivity involved (in curies) are sometimes considerably larger, and the penetrating nature of the radiation may require substantial shielding within the shipping containers. The same circumstances may apply to some industrial applications of radioisotopes. Equipment used to preserve food by irradiation, to sterilize medical goods through high doses of radiation, or to analyze the integrity of welds in thick steel plates through radiography may incorporate far larger amounts of radioactive material than those needed as industrial tracers (e.g., to locate leaks in a pipe network). To facilitate both the transportation and the general handling of some of the large-quantity materials, they are sealed inside high-integrity, welded metal capsules.*

In some cases smaller quantities of nuclear material are also encapsulated. One example is the plutonium-238 power source that is implanted directly into the chests of heart patients who need pacemakers. In that instance the metal walls also provide an adequate radiation shield, because plutonium's alpha emissions are easy to block. Even in the case of other types of radioactive material, however, encapsulation changes the ground rules so far as transportation is concerned.

*If radioactive decay within a large shipment is likely to build up a substantial amount of heat in transit, there must also be heat-dissipating fins, fans, or some other cooling mechanism to limit the temperature rise.

The reason is obvious. If encapsulated nuclear materials were released accidentally from their *outer* packaging, they *might* offer some hazard via direct radiation; but the sealed capsules would certainly present little danger of having their contents absorbed by living organisms and little possibility of spreading radioactive contamination. That is why Appendix I shows two different numbers as the maximum quantity of each material that may be shipped in a Type A package. The A_1 limit applies to *encapsulated* material, while the lower A_2 limit governs the same material when it is *not* in this special form.

Type A packages are used for the overwhelming majority of nuclear shipments, so they present great variety in appearance and design. As Figure 8 shows, different techniques are used for solid and liquid shipments. A Type A package might be made of fiberboard, wood, or metal; and it could be of almost any shape or size, depending on which of the hundreds of types of nuclear material it is intended to contain. For example, a very common Type A package is the conventional 55-gallon metal drum used for low-level waste and also for "feed materials" in parts of the reactor fuel cycle.

Because the amount and nature of its radioactive contents are limited by regulation, a Type A package need not be indestructible—or even nearly so. Nevertheless, to win approval for this use, a package design must be rugged enough to survive a series of tests that add up to the equivalent of some pretty rough handling, which is anticipated by the Department of Transportation and the Nuclear Regulatory Commission in "normal transport conditions".

Can't you imagine a radiopharmaceutical carton being allowed to sit on a loading dock somewhere during a rainstorm and then being handled with something less than "tender loving care"? So can DOT and NRC! That's why they specify that any Type A package must be able to prevent loss or dispersal of its contents (and also retain its shielding efficiency) even if all surfaces except the bottom are soaked and it is then dropped 4 feet. Similarly, regulatory officials have a very clear idea of what aircraft baggage

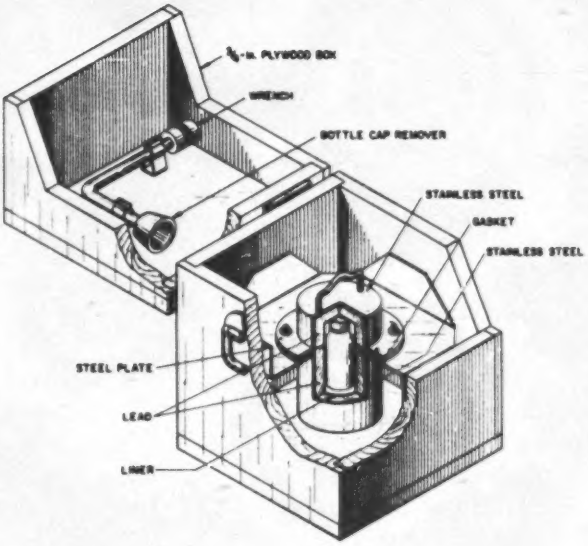
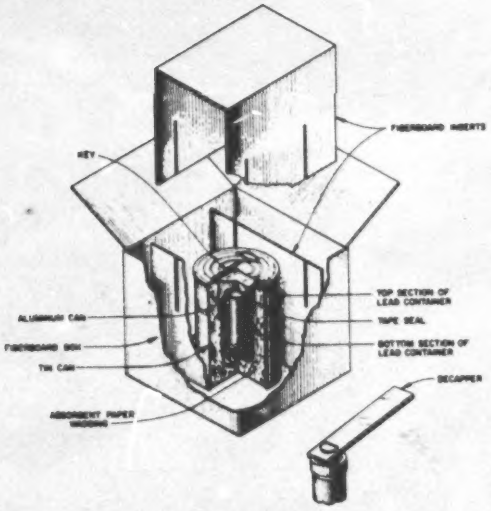


Figure 8 Two examples of Type A packaging—

compartments are like. That's why the rules specify that a Type A package must be able to withstand temperature ranges from 130°F to 40° below zero, depressurization to half the normal atmospheric conditions at sea level, puncture forces, and a great deal of vibration.

As one might imagine, there are special regulations for *liquid* nuclear materials. They must be packaged within a leak-resistant and corrosion-resistant *inner* container. The outer container must be able to survive a 30-foot drop without leaking, and its interior must have enough absorbent material to soak up at least twice the volume of liquid contents in case breakage *does* occur.

Requirements for Type B packages will be discussed in more detail in a later section, on page 33, but briefly they are intended to keep their contents intact under much more severe stresses, such as those that would be produced by a major traffic accident, a fire, or even an explosion.



for liquids (left) and solids (right).

One of the most common misunderstandings about the transportation of nuclear material arises in the handling of nuclear *wastes*, whether these originate in the power plant fuel cycle or in medicine and industry. Regarding *high*-level wastes there should be no question. Material such as the fission-product residue of fuel reprocessing would *always* have to move in Type B packages. But what about the filter paper used in the laboratory analysis of some mildly radioactive solution? What about discarded packing materials that might be slightly contaminated? What of the hundreds of items that might absorb some radioactivity as a result of industrial applications? *Those* things are "nuclear waste", too, but they contain such low concentrations or quantities of radioactivity that they would produce very little hazard to the public or to the environment if they escaped. In keeping with the overall policy of avoiding *unnecessary* public exposure to radiation, such low specific activity (LSA)

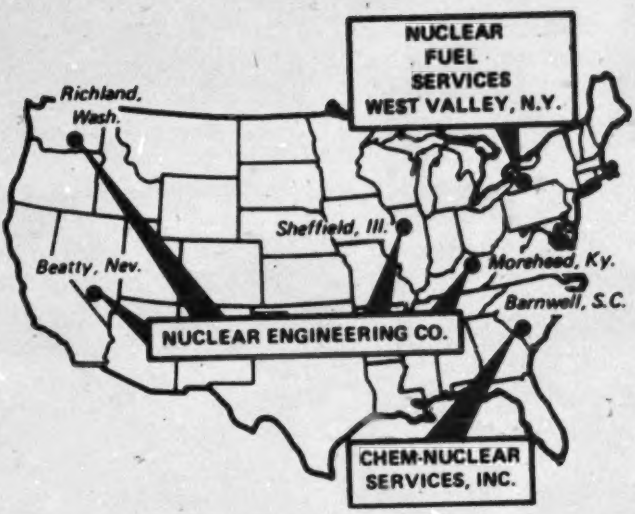


Figure 9 Commercial burial sites for low-level solid waste.

materials are controlled, collected, and shipped periodically to approved burying grounds where they are put into deep trenches and covered with earth by bulldozers. (Figure 9 shows the locations of such sites.) For the most part these LSA materials are shipped in steel drums or boxes, but this is more a matter of convention and convenience than necessity. Any normal industrial packaging will suffice, and no special transportation equipment is required.

Thus we see that there is an enormous variety of shipping containers for nuclear material, either inside or outside the fuel cycle. They may range from a cube you could hold in one hand to something the size of a boxcar. In weight, they go from a pound or two to many tons.

Among heavy shipments, most of the weight is often added by shielding. Lead is frequently used for shielding because it is cheap and easy to fabricate into odd shapes, but it is being replaced increasingly by steel, "depleted uranium", and even tungsten in certain cases because of the higher melting points of the latter materials. Depleted uranium is, in a sense, a product of the nuclear fuel cycle itself. It is what is

left over after uranium-235 has been concentrated within a small part of the original feed material during the enrichment process. Depleted uranium, which consists almost entirely of uranium-238, is technically still radioactive itself (although barely so). It is certainly no biological hazard. Although depleted uranium costs more than lead, it is a more effective shield material because of its very high density. This may be important when shipping volume and/or weight are limited.

Occasionally, even concrete is used as a shipping shield. The massive 11-ton cask, mounted on a 2-ton skid shown in Figure 10, is used to deliver tiny amounts of such intensely radioactive man-made materials as californium-252, which is beginning to find industrial value in uses like the logging of deep wells.

The number of nuclear shipments of all kinds may seem very high, but it is wise to keep this in perspective. All together, more than 30 billion individual containers of *other* hazardous material—constituting over 100 million separate shipments—move along the roads, rails, and airways of the United States each year. These contain acids, explosives, poisons, and all sorts of flammables. There are roughly 100

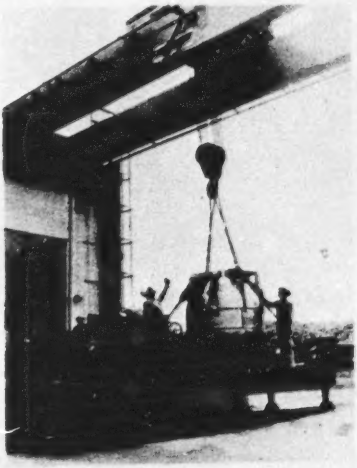


Figure 10 A small fraction of an ounce of californium-252 (an intense source of neutron radiation) requires a concrete and depleted-uranium shipping cask this size.

such shipments for every *one* of nuclear material. But the nuclear industry grew up in an atmosphere of heavy emphasis on safety, and there are few who quarrel with the strictness of the transportation rules that have evolved for them thus far. In the next section, we will look at some of the legal requirements in more detail.

Transportation Rules: Who? What? Why? How?

The two federal agencies that share the major responsibility for regulating the transportation of nuclear material are the Department of Transportation (DOT) and the Nuclear Regulatory Commission (NRC). In order to cover all modes of transport, DOT exercises its authority through four of its operating units: the Federal Highway Administration (FHWA), the Federal Railroad Administration (FRA), the Federal Aviation Administration (FAA), and the U. S. Coast Guard.

Ordinarily, federal transport regulations would cover only movements across state boundaries, but their application to nuclear materials is broader than that. Because an individual or organization must be licensed by NRC even to *handle* significant quantities of nuclear material (such as those in the fuel cycle), that agency's jurisdiction extends to some intrastate movements as well as interstate transportation. Furthermore, DOT has been empowered specifically to regulate certain intrastate movements of any nuclear shipment that originates *outside* the United States (for example, a package from abroad that enters the Port of New York and is destined for someplace else in New York State).

Because the authority and expertise of DOT and NRC overlap, their cooperation in the field of regulation has been governed by a series of "Memoranda of Understanding" to eliminate either duplication or conflict. Under these agreements DOT establishes general regulations for shipping and carriers, including packaging standards, limits on size and contents, labeling, in-vehicle loading restrictions, inspections, shipping documents, vehicle operation, and accident reporting. NRC sets up special packaging standards for highly radioactive materials, such as spent fuel, high-level waste, and large amounts of radioisotopes. NRC also has a role in recommending performance standards that relate to the possible adverse effects on either shipping workers or the

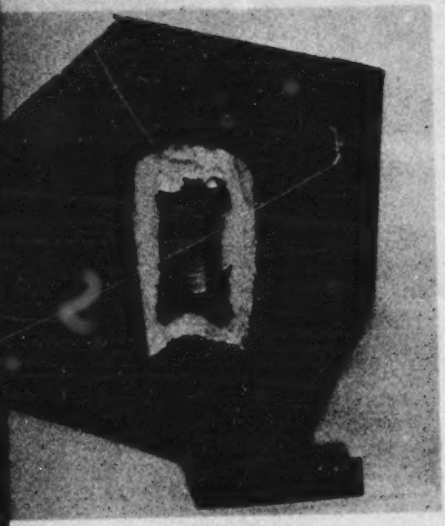


Figure 11 Cutaway of a shipping container for cobalt-60, an isotope used for medical purposes.

general public due to radiation and radioactivity of the contents.

In shipping all but very small amounts of nuclear materials, the design of the package must meet DOT's specifications or be approved in advance by NRC. The safety analysis of the design is supplemented by "torture tests" aimed at making sure that the container system is adequate for its intended use. Hundreds of different nuclear material package designs have been approved now, ranging from those that weigh only a few pounds to massive casks weighing over 100 tons. NRC also requires each licensee to develop detailed programs for controlling and verifying the high quality of material and workmanship used in fabricating the packages as well as the use and maintenance of the containers after delivery to the shipper.

The transport regulations themselves have evolved considerably over the years since the Nuclear Age began, and continued change in some details can be expected. Current criteria are based on more than two decades of experience in shipping many types of material. Many years ago, all nuclear materials were treated by the old Interstate Commerce

Commission rules as a type of poison, and very little significance was attached to the great differences in nature and relative hazards of various nuclear material. Now, however, more complex and sophisticated regulations are enforced at both the national and international level (in the latter instance through the International Atomic Energy Agency). Similarly, most states have adopted regulations that require shippers of radioactive material within their boundaries to conform to the federal packaging, labeling, and marking requirements, thus making possible more rigid monitoring.

States also become involved in regulating the shipment of spent fuel from power plants because of the gross weight limits placed on trucks (which vary from state to state), but those restrictions have nothing to do directly with the radioactive nature of the material being transported. In addition, radioactive cargoes and certain other potentially hazardous shipments are banned from some tunnels, bridges, etc. (or limited to travel under escort or during certain time periods) so as to avoid accidents that—while not any particular threat to public safety—might hold up local traffic inordinately.

Federal rules have two fundamental objectives: 1) to protect both transport workers and "innocent bystanders" from potential hazards under normal conditions, and 2) to give the maximum practical protection in the case of any foreseeable accident. As to the first goal, hazards can be subdivided into radiation, heat, and (in regard to some material) accidental nuclear criticality. In all respects they can be controlled by limiting the radiation and temperature levels on the outside of each package and by enforcing certain stowage and segregation provisions. But adequate labeling is essential, and the labeling itself is tied directly to a carefully computed safety indicator called the Transport Index.

Like the rem (the standard gauge of radiation effect on living tissue, which is discussed on pages 51 and 52), the Transport Index (TI) is a measuring unit that takes several different factors into account. For instance, a TI of 1 is

assigned to a package that emits a radiation dose of 1 mrem per hour at a distance of 3 feet from its surface, and the TI for any other package varies in proportion to the dose at that standard distance. Thus, a dose of 10 mrem/hr at that point raises the Transport Index for the package to 10; a dose of half a millirem per hour means that the TI is 0.5.

But some nuclear materials are also capable of sustaining a nuclear chain reaction, giving rise to a different sort of handling hazard (see discussion of criticality on page 12). When fissile isotopes of uranium or plutonium are shipped in certain quantities (generally speaking, in packages containing more than about half an ounce each), some additional form of control is desirable to make sure that a number of them won't be assembled in one place so as to produce a critical mass and geometry. Therefore, a Transport Index may be assigned on the basis of the amount, nature, and purity of the fissile material involved—making allowances if neutron-absorbing material has been incorporated in individual containers to discourage chain reactions.

In this regard the assignment of a Transport Index is fairly complicated, but the net result is that if the *total* TI for any vehicle or storage area is 50 or less there will be an adequate safety margin to avoid any accidental chain reaction. In fact, the standards guarantee that there would be no danger of criticality even if two "maximum" shipments wound up side-by-side by mistake, *and* all the packages were damaged simultaneously, *and* the whole business was somehow submerged in water.

Clearly it is only a coincidence if the "radiation TI" and the "fissionability TI" are identical, but when they differ, the package in question is always assigned the *larger* of the two numbers for shipping purposes. That makes the system even more conservative. And in certain cases federal rules require that nuclear materials be shipped on an "exclusive use" basis, which normally means that the individual or organization sending the material loads the shipment directly, and that it is unloaded by the consignee, with no other goods allowed aboard the vehicle during transit.

Figure 12 Package label.

The Transport Index of each package must be noted on its warning label. Each package must bear at least two identical labels on opposite sides to increase visibility. Readily recognizable and distinguishable markings on various types of labels give transport employees an additional quick clue as to the levels of radiation involved in shipments (see Figure 12.)

After containers and shipping accessories have once been used for nuclear material, they may contain some residual contamination, so "Empty" labels are used to designate them. Their outside surfaces must be cleaned before shipping, and the radiation at the surface must be reduced to 0.5 mrem/hr or less. Furthermore, even an empty container must be closed securely during its return trip to the originator.

Similar rules apply to any vehicle that is used regularly to carry significant amounts of nuclear shipments; and when such shipments are actually aboard, the vehicle must display placards with the inscription "Radioactive" on its front and rear and on each of its sides.

The upper limits of radiation for a shipment depend on the conditions under which the material is transported. Ordinarily the radiation at the surface of any package is limited by DOT regulations to no more than 200 mrem/hr in order to restrict the direct exposure to anybody who might handle it. And at 3 feet from the surface of any single package the normal limit is 10 mrem/hr, which equals a Transport Index of 10. Surveys over many years in areas where a high volume of nuclear materials packages are handled or stored indicate that this guideline will keep workers within current industrial exposure limits.

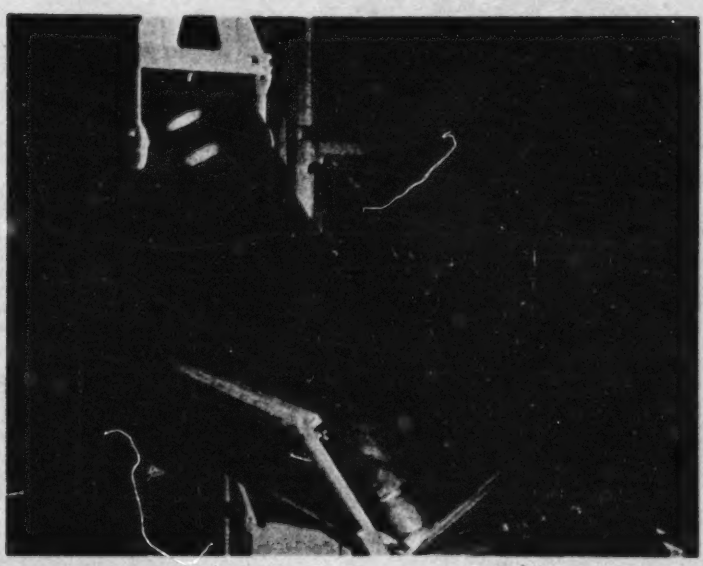


Figure 13 A spent fuel cask is removed from its truck-trailer at the reprocessing plant. The foldaway screens on either side of the flatbed limit access to the cask during transit.

A TI of only 10 would be very difficult to achieve with a spent fuel cask, so such a shipment is invariably made on an "exclusive use" basis. Thus, when the spent fuel cask is shipped within a closed truck or rail car, the main body of the vehicle itself becomes in effect the "package". The radiation level at the surface of the *vehicle* then must not rise above 200 mrem/hr; and at any point within 6 feet of the surface it may not exceed 10 (thus producing an effective TI of less than the maximum limit of 50 for the shipment as a whole). Routinely the carrier takes steps to keep people along the route from remaining close to the surface of the truck or car for any prolonged period; and the exposure in the driver's compartment (or anyplace else near a shipment that is normally occupied by people) must be kept below 2 mrem/hr. The radiation reaching bystanders along the way (even those who might sneak up close for a peek while the driver is having lunch at a diner) is bound to be very low.

In the case of air shipments (which have accounted recently for about three-quarters of all movements of radioisotopes), several changes in FAA regulations were recommended in 1974 that would reduce even further the exposures of both passengers and crew members. Under one proposed amendment, the maximum TI of any single airborne package would be cut from 10 to 3. A series of studies over more than a year has also shown that the minimum permissible separation distances between personnel areas and the surface of radioactive material packages could be further increased.

As has already been pointed out, all approved shipping containers are designed to keep their particular radioactive contents intact in spite of the normal jouncing and jostling the packages may receive in any mode of transportation. Nevertheless, other measures are taken to guard against the possibility of leaks or any other mishap or human error that might leave the surface of a container contaminated with radioactivity that could "rub off". DOT requires that the levels of removable contamination be determined by a "wipe test" and radiation monitoring equipment before shipment. At the receiving end, NRC requires its licensees to pick up

shipments* promptly in cases where they are not delivered directly to the premises, and it insists that they monitor the external surfaces of each package as soon as practicable in any event. They must report immediately to the NRC and the carrier if more than one hundred-millionth of a curie can be detected in a 100 square centimeter area—about 4 inches square. This inspection must be made within 3 hours if the shipment arrives during normal working hours, and always within 18 hours.

That summarizes the major regulations under all normal circumstances except for the limitations on temperature, which are simple. DOT regulations provide that the temperature of any accessible surface may not rise above 122°F as a result of radioactive decay within its contents unless the material is being shipped under "exclusive use" conditions. Then the temperature of the shipping cask surface is allowed to rise to 180°F.

*There are some exceptions to this rule, including materials shipped in "special form", those that are exempt from labeling requirements, small quantities of certain materials shipped in nonliquid form, and some with very short half-lives.

How Safe Is "Safe"?

It's obvious that few shipments approach the maximum legal limits in all categories. Steps taken to reduce temperature may reduce radiation at the same time. In meeting radiation requirements at a certain distance from the surface, the radiation level right *at* the surface may be forced down well below the maximum allowed there. And—especially for some materials in the nuclear fuel cycle—size and weight alone may be limiting factors. In the case of fresh fuel, for example, as many as 20 fuel bundles of a certain design *could* be loaded on a single vehicle without exceeding in any way what DOT and NRC have judged to be safe limits. But the fact is that the containers for them are so large and heavy that no more than six or seven are ever placed on one truck.

Safeguarding public health and safety under *extraordinary* transport conditions also involves a conservative approach. This is especially evident in the requirements for Type B packages—the containers that must be used for larger amounts of radioactivity (see Appendix I). These are defined, essentially, as packages that can survive an almost incredible amount of abuse without allowing their contents to disperse. Establishing criteria for them has involved careful analysis of such "real life" transport accidents as 80-mph truck crashes, unusually hot chemical fires, and TNT explosions.

A Type B package need not be very large, and in some cases it may not even be very heavy. Twenty curies of plutonium, for example, might represent a very small volume; and little shielding is required because of the type of radiation it emits. But plutonium, besides being fissile, is extremely toxic; and the human body has trouble getting rid of it once it is absorbed. So if more than 20 curies of plutonium are being shipped, they must be carried in a Type B package—the kind of container that has demonstrated its ability to maintain integrity after the following events, which are listed in order:

1. A 30-foot free fall onto an unyielding surface with the package landing on its most vulnerable point (usually a corner);
2. A "puncture test"—dropping 4 feet onto a steel pin—again landing in a way that will produce the maximum damage;
3. Exposure for 30 minutes in a furnace so that the heat completely envelops it and never drops below a temperature of 1475°F;
4. Total submersion in water.

Quite often, when skeptics hear these requirements, they promptly speculate about potential accident conditions that seem to exceed the specifications. What would happen if the package fell thirty-*one* feet? Suppose a truck carrying radioactive material collided with another carrying some flammable cargo like propane, which burns at a temperature *above* 1475°F? How about a fire that lasts an hour or so?

It is true that *any* package can always be made stronger, and that conditions worse than *any* "design basis accident" can always be imagined. But the people who propose these "what if . . .?" questions overlook some important facts.

First, these engineering tests are far more demanding than the "real life" conditions that appear to parallel them. A drop of 30 feet onto a rigid, *unyielding* surface, for instance, would be equivalent to a *much* longer fall onto sand and gravel in a streambed. Furthermore, the engineering tests are performed with a bare container, although in practice a heavy shipping container would normally be attached to the bed of a vehicle or surrounded by some outer framework that would help to cushion any impact. And of course there is no guarantee (or even any great likelihood) that accidental impacts will always be at a container's weakest point, which is a requirement of the engineering test.

The effects of the carefully staged "fire test" are similarly exaggerated. Under actual fire conditions, the temperature rises gradually and subsides in the same way, so that 30 minutes of a constant 1475°F in a furnace is really the damage equivalent of a much longer fire. Furthermore, the temperatures that a container could *actually* reach, in fires

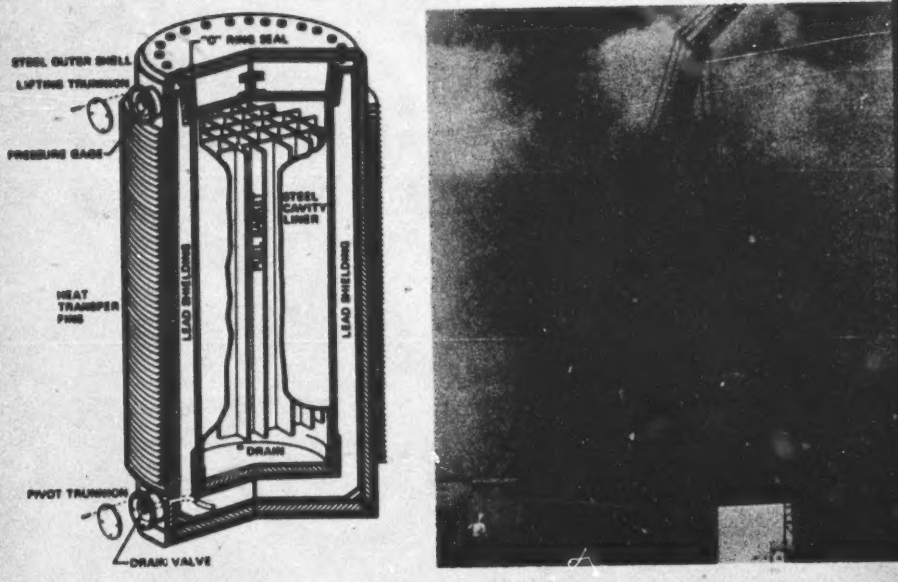


Figure 14 On the left is a cutaway of a typical multi-bundle shipping cask for spent fuel. On the right a shipping cylinder is readied for a 30-foot test drop onto 4-inch-thick armor plate.

involving hot-burning materials like acetone, propane, or benzene, are well below the theoretical "flame temperatures" or those produced under laboratory conditions with those materials. This would be especially true in a long-lasting fire around a noncombustible shipping container.

Aside from all this, however, it should be kept in mind that the engineering standards for Type B packages are *minimum* requirements. There is no reason to assume that a cask which can survive all these tortures intact will crumble away as soon as it is subjected to a slightly greater impact or slightly hotter fire.

As a matter of fact, the composite tests have been designed to be more demanding than anything a shipping cask is truly expected to encounter. This includes all sorts of nonnuclear shipping accidents that have been analyzed by the

Figure 15 Above, a spent fuel shipping cask is completely engulfed by flames from burning jet fuel during fire tests. Below, an obsolete shipping container and pallet were dropped 2000 feet from a helicopter onto land. The 16,300-pound object survived the impact.

Government officials responsible for safety—high-speed train and truck collisions, tank fires, explosions of ammunition,* falls from bridges or overpasses, etc.

Needless to say, any analysis of accidents that might befall a shipment of *hot* radioactive materials must consider the possibility of cooling system failures. If cooling equipment associated with a cask of spent fuel were put out of commission in a highway accident, for instance, the heat of normal radioactive decay would cause the cask's temperature to climb. Calculations show that it might rise to as much as 700°F, in fact, but there would be no danger of melting the cask wall itself. Although this might pose serious handling difficulties temporarily—just as many accidents present other "clean-up" problems—there would be no reason to fear a dangerous release of radioactivity.

For the most part, the tests on new package designs are carried out through the use of scale models, mock-ups, and computer analysis, but full-sized casks weighing many tons have also been subjected to testing. In some cases these have actually been tested until they failed—with the test results indicating substantial margins of safety between the design requirements and the point at which they lost their mechanical integrity.

*Although the consequences of such an accident were studied, DOT regulations forbid adjacent shipments of materials like conventional explosives and radioactive substances.

Accidents *Do* Happen

In view of the fact that millions of shipments of radioactive material have taken place over the years in this country, it is somewhat surprising at first to learn how few have been involved in accidents of any sort. Several hundred accidents have been reported, and in most cases these resulted in no increase in radiation levels at all. No Type B containers have *ever* released any radioactivity as a result of fire or impact, and even Type A packages have produced only minor releases. As of this writing, no transportation accident of any kind has ever resulted in a fatality or in any perceptible injury due to the radiological aspects of the shipment.

There *have* been instances in which a road accident in itself caused the death of a driver. There have been other cases in which faulty packaging produced higher radiation levels in transit or storage areas than permitted by regulation. There have been a number of times when Type A shipping containers failed under some unusual stress and leaks took place. And there have even been a few cases when accidents involving radioactivity cost tens of thousands of dollars to clean up. By comparison, a typical serious train derailment costs millions of dollars in property damage. But the fact remains that careful planning, strict rules, and tough enforcement have prevented any threat to public health or safety based specifically on the movement of nuclear materials. That's quite a record.

What happens if a train or truck bearing those "Radioactive" placards is damaged in a wreck? The answer is another interesting and important part of the story of nuclear transportation. No matter where or when the incident occurs, the "Radiological Assistance Program" may be called into action almost immediately if there is need for it. The program involves interagency cooperation among a number of groups, but under most circumstances the principal personnel are associated with the Energy Research and Development Administration, the Department of Defense, and/or state and local health departments. Transport workers

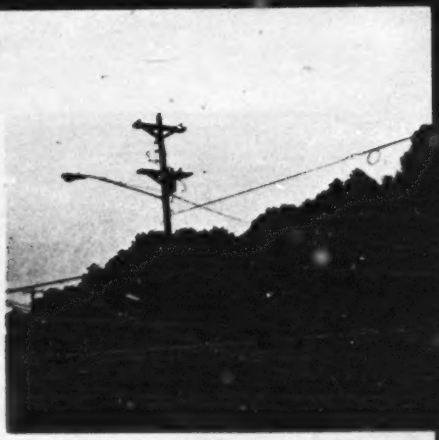
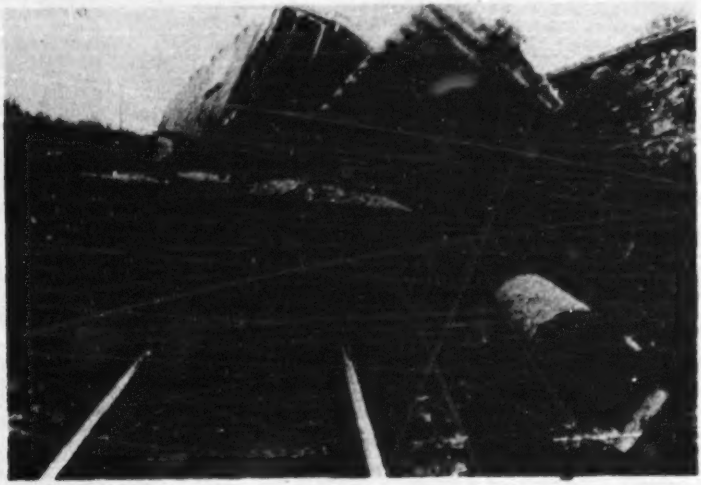


Figure 16 In the highway accident shown above, a truckload of cylinders containing radioactive material was overturned and had to be righted, but the cylinders did not break loose from the truck bed. No leakage of material occurred, and there was little damage to the cylinders. In the train accident shown below two containers of uranium hexafluoride (UF_6) pulled loose and one was struck by the wheels of several freight cars as the train derailed. None of the contents escaped, even though this type of container is not designed to be as rugged as those used for shipping material of higher level radioactivity.



ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
REGIONAL COORDINATING OFFICES
FOR
RADIOLOGICAL ASSISTANCE
AND
GEOGRAPHICAL AREAS OF RESPONSIBILITY

	Regional Coordinating Office	Post Office Address	Telephone for Assistance	DDD Area Code
1	Brookhaven Area Office	Upton, L. I., N. Y. 11973	345-2200	516
2	Oak Ridge Operations Office	P. O. Box E, Oak Ridge, Tenn. 37830	483-8611 Ext. 3-4610	615
3	Savannah River Operations Office	P. O. Box A, Aiken, S. C. 29801	N. Augusta, S. C. 824-6331, Ext. 3333	803
4	Albuquerque Operations Office	P. O. Box 5400, Albuquerque, N. Mex. 87115	264-4667	505
5	Chicago Operations Office	9800 S. Cass Ave., Argonne, Ill. 60439	739-7711 Ext. 2111 duty hours Ext. 4451 off hours	312
6	Idaho Operations Office	P. O. Box 2108, Idaho Falls, Idaho 83401	526-0111 Ext. 1515	208
7	San Francisco Operations Office	1333 Broadway, Oakland, Calif. 94612	273-4237	415
8	Richland Operations Office	P. O. Box 550 Richland, Wash. 99352	942-7381	509

Figure 17

who deal with radioactive material, state police, and local authorities who normally respond to transportation accidents of any kind are taught to notify the nearest Regional Coordinating Office for Radiological Assistance (see Figure 17) as soon as there is any indication that an accident involving release of radioactivity has taken place. A radiation emergency team from an ERDA center, the local or state health agency, or one of more than 300 military installations across the country will be dispatched to the scene as quickly as possible.

The captain of a Radiological Assistance Program (RAP) team is not empowered to take over the total accident operation; that remains the responsibility of local public safety authorities. But he does offer whatever specialized help is necessary. The team is equipped to monitor for radiation and to evaluate hazards promptly. Members can give advice or aid in medical treatment, and they can provide laboratory analysis services in case anybody has been exposed to radiation. The team can sample the air, water, soil, and surrounding area for possible radioactive contamination, and it can conduct or supervise decontamination procedures when necessary. Almost of equal importance is the team's ability to provide accurate information to the public and the news media. Especially in light of the fact that most such accidents produce only minor radiation effects, the greatest danger when one takes place can easily be public misunderstanding or panic.

There are a few commonsense rules that apply in situations like this. One is to stay clear of smoke or vapors except to rescue people. Another is to keep sightseers at a reasonable distance—several hundred yards if this is practical—and to discourage them from picking up souvenirs just as they might in any other kind of accident. Overall, however, it is best to remember that not all radioactive material is alike and that the greater its potential danger the less likely it is that any will escape (because of the progressively more stringent packaging and handling rules).

The "scare stories" about the danger of radioactivity being spread over wide areas as a result of transport accidents

Figure 18 A "RAP" team at the scene of an accident.

simply do not agree with the facts, even if it is assumed that a high-level container like a spent fuel cask did split open. Most of the contents would probably remain inside despite a rupture, and those that did escape would not all produce maximum damage. Gaseous fission products within spent fuel would be diluted rather quickly in the atmosphere if they got out. Semi-volatile materials (like cesium), on the other hand, would settle out promptly within a small radius of a fire or explosion so that any cleanup necessary would still not be an unmanageable problem. It is perhaps unrealistic to assume that the *perfect* record on injuries in nuclear material transportation can be sustained indefinitely, but fears of a *catastrophic* release are even less realistic.

Insurance coverage on shipments of radioactive material is an extremely complicated subject. To a large extent, "third parties" who might suffer injury or property damage from radiation while the material is in transit are protected by liability coverage for either the sender or the receiver (or

both). For movements of most material within the nuclear fuel cycle, this includes a combination of commercial insurance required by law and government indemnification under the Price-Anderson Act. For shipments of medical and industrial radioisotopes, most of the coverage may be provided under comprehensive general liability policies. In some cases, all or part of the coverage may be provided by industry-wide insurance pools. But at any rate there is no doubt that adequate coverage is available for any type of radioactive shipment.

In spite of the excellent safety record of nuclear transportation to date, there are periodic proposals to make its regulations even tighter. It is often urged that shipments of high-level nuclear materials (such as spent fuel, for example) be restricted to certain routes. It has also been suggested that rail shipments be allowed only on special trains devoted entirely to that purpose. Escorts have been proposed for each and every vehicle. All these ideas have been considered, but so far the weight of evidence seems to be that they are simply unnecessary at present.

Shipments of hazardous materials of any kind are already required to be routed so as to avoid major cities and congested areas insofar as practicable. If current shipping distances were increased *substantially*, however, or if the shipments had to follow less-traveled routes that were not as

Figure 19 A self-powered mobile manipulator system developed by the AEC can help to clear radioactive material from the scene of an accident while TV monitors give the operator a safe closeup view.

well maintained, the number and consequences of accidents might actually increase instead of decline. The fact is that the present system has proved so successful that changes to it should not be made lightly. Nevertheless, flexibility is important, too, and regulations certainly will continue to evolve.

This is particularly true in regard to air transport. As the result of several widely publicized incidents involving human error, various proposals have been made to stiffen the monitoring of planes, flight personnel, and air shipments; and some such actions will probably be taken. In fairness, however, it should be pointed out that the radiation levels associated with the incidents in question were actually quite low. Nobody was hurt or even close to being hurt. No degree of regulation is likely to eliminate *all* chances of mishap, but the social benefits that result from air shipments of radioisotopes ought to be weighed against the limited risks involved. The frequently heard suggestion that nuclear shipments be restricted to planes that carry only cargo is clearly impractical if the use of short-lived isotopes in medicine and research is to continue at all. Relatively few areas of the U. S. are served by cargo-only planes, and speedy delivery cannot be assured except in the baggage compartments of passenger aircraft.

Are We Ready for Tomorrow?

Transportation of radioactive materials throughout the Nation is bound to increase overall. The rise in the absolute *number* of shipments may not be very dramatic in the decades to come, but we can assume that much more radioactivity will be involved because of increased movements of spent fuel and high-level waste within the nuclear fuel cycle.

On the average, more than 100 shipments of radioactive material each year move in and out of each operating power reactor site. More than half of those include relatively low levels of radioactivity, but the growing role of nuclear energy in the U. S. suggests that the number of Type B casks being transported during the 1980s is likely to reach the tens of thousands annually. Exact numbers are difficult to project because this depends on the size of each shipment, and the optimum balance (both for safety and economy) is still a matter of research.

Earlier shipping casks for spent fuel, which carried only a single bundle each, are clearly not suitable for the future. Various multi-bundle casks have been approved for use now, and others are under review or on the drawing boards. Because of weight limitations on highways, rail casks will probably always be able to accommodate larger quantities than trucks in a single trip, but some power plant sites are not served by rail at all. Furthermore, an AEC study* showed that while overall accident rates per mile are similar for rail and highway there is a somewhat greater chance of a really serious wreck in the case of train transport. In either case, NRC and DOT know that it is not humanly possible to prevent transportation accidents completely, so they have concentrated on making sure that Type B packages can *survive* them. So far they have done so in every case; the

*See *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants* (WASH-1238) listed in the bibliography on page 55.

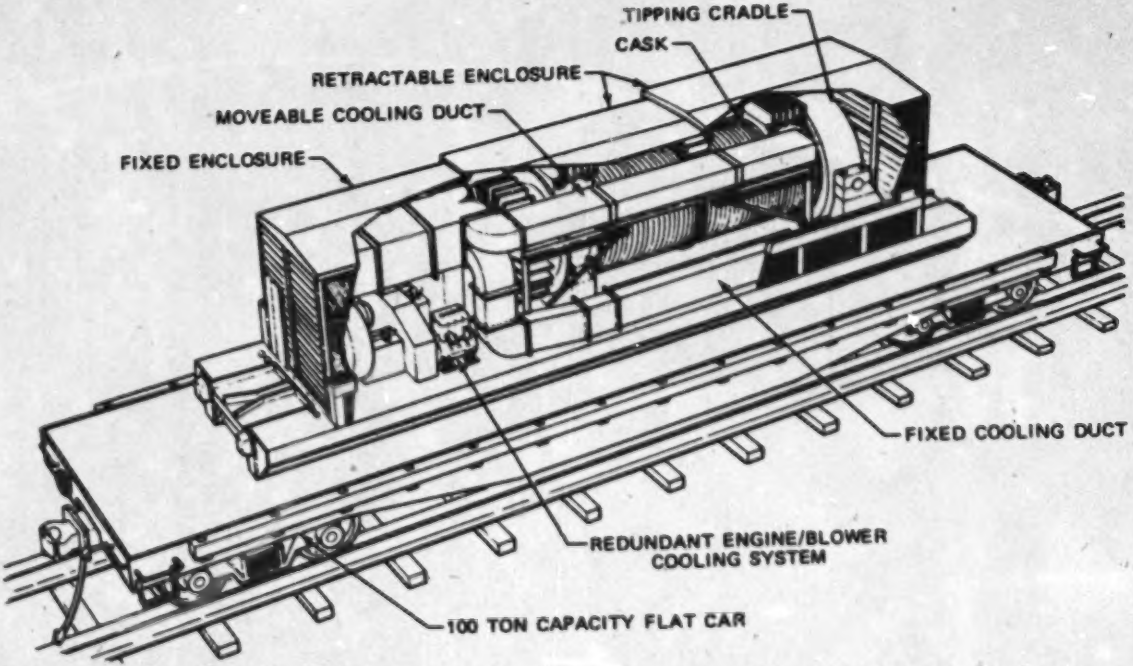


Figure 20 This railroad shipping cask can carry up to 18 fuel assemblies on each trip.

packages have *never* released their contents inadvertently under any circumstances.

Research and development efforts continue, and every 3 years since 1965 the Federal Government has sponsored an international symposium on the packaging and transportation of radioactive materials in order to promote the free exchange of expert ideas and improvements in safety technology. Computer codes are constantly being refined, too, so that new container designs can be analyzed more precisely in a more comprehensive manner than physical tests alone could accomplish. Leak detection is also becoming more sophisticated, as are closure techniques for unescorted shipping containers and armored vehicles used to safeguard fissile materials against possible theft.

Research and development will probably never end, because techniques to assure proper safety and environmental protection must stay ahead of a constantly changing transportation picture. It is important also to improve methods of estimating potential shipping hazards, to improve practical technology for minimizing such dangers, and to keep the costs of safe transportation within reasonable bounds.

Container standardization is a long-term goal, but it is particularly hard to achieve in the fuel cycle because there was such great diversity until recently in fuel element design. NRC's "design guides" for shipping casks are a step in that direction, however, and the emphasis on standardization for commercial reactors themselves will also contribute. Standardized design approaches have already proved successful in developing safe radioisotope-fueled thermoelectric generators, which are packages of high-level radioactive material in themselves. In fact, these SNAP* generators already hold the long-distance transportation record for radioactive shipments, because they were taken to the moon during the Apollo program (see Figure 21).

Getting back to earth, authorities realize that even the best transport regulations will not produce a continued record of safety unless they are rigidly enforced. Besides

*SNAP is an acronym for "*Systems for Nuclear Auxiliary Power*".

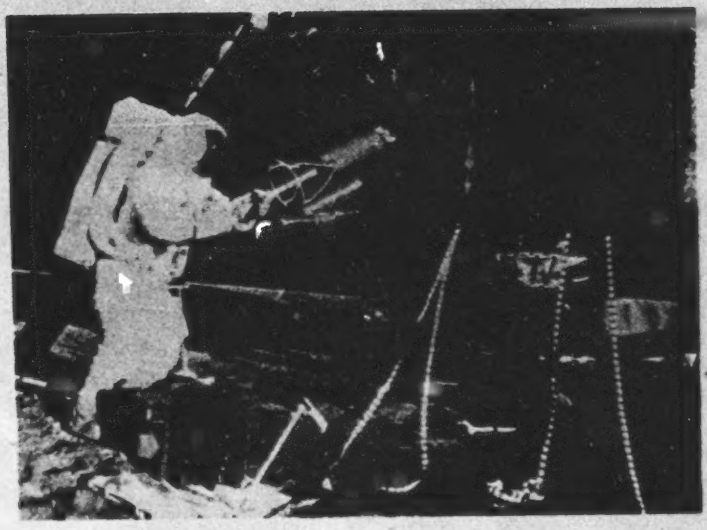


Figure 21 Radioisotope-fueled power sources have traveled with man to the moon and are scheduled next for delivery by rocket to Mars. The arrow points to the SNAP-27 thermoelectric generator that provides approximately 73 watts of power for instruments left on the moon by the Apollo-12 astronauts. The power is generated by converting heat from the radioactive decay of plutonium-238 into electricity through a thermoelectric process. Astronaut Gordon Bean is removing the plutonium-238 from its container before inserting it into the generator.

expanding their own regulatory system to keep pace with the growth of the nuclear industry, federal officials have encouraged state and local authorities to help ensure conformity with radiological standards in transportation.* States

*Under the legal doctrine of federal preemption, states are not permitted to establish their own individual radiological standards for shipments, but they *can* play a significant role in monitoring and enforcement—if only by announcing and pursuing a policy of spot checks. State and local officials are also often in a better position than federal authorities to investigate accidents in detail and to analyze contributing factors. Recommendations by state and local officials based on such experience should be considered in carefully updating and modifying federal regulations as time goes on.

are also being urged to reconcile differences in *non*nuclear transportation laws whenever possible if such differences are blocking standardization.

Federal regulatory officials will continue specialized transport surveys like those conducted in 1973 and 1974 at airports and aboard passenger aircraft that also carry radioactive cargo. As nuclear shipments of all kinds have increased, the Department of Transportation and the Nuclear Regulatory Commission have increased surveillance efforts by using "compliance teams" in the field to inspect conditions in every phase of transportation. Federal regulators have not hesitated to levy fines against licensees and shippers when rule violations are uncovered regardless of whether any actual damage results from the infraction. And there are increasing educational efforts about the reasons for and importance of such regulations, both within the nuclear industry and among the general public. State and local officials will have an essential role, too—especially in responding promptly and knowledgeably to any emergency situation, and also in helping to enforce a unified system of regulation that will maintain its excellent record of protecting people, property, and the environment. Every one of these steps is vital if the U. S. nuclear program is to meet its avowed goal of keeping radiation exposures for all Americans "as low as practicable".

Appendix I Packaging Restrictions for Some Common Radioactive Substances*

Type of Material	Maximum Number of Curies That May Be Shipped in Type A Package†		Requirement for "Type B" Packaging
	A_1 —If Welded Inside Metal Capsule	A_2 —If Material Not Encapsulated	
Plutonium-239	2.0	0.002	*Any* quantity larger than those specified as A_1 or A_2 respectively *must* be shipped in Type B packages, which are designed to limit releases of the contents to a very small fraction of the A_2 amounts, even in case of a major collision, fire, explosion, etc. For more details about Type B package specifications, see pages 33–37
Cesium-137	30.0	9	
Iodine-131	40.0	10	
Strontium-90	10.0	0.4	
Cobalt-60	7.0	7	
Phosphorus-32	30.0	30.0	
Tritium (a radioactive form of hydrogen)	1000.0	1000.0	

*In 1974 the International Atomic Energy Agency adopted restrictions of this sort for more than 250 specific materials, also prescribing methods by which limits should be determined for other radionuclides or for mixtures. The U. S. Department of Transportation has indicated its intention of adopting these rules by reference, and replacing the somewhat less specific regulation by "Transport Group" that had been in effect for many years.

†Without going into detailed technical specfications, a Type A package may be described as any shipping container sturdy enough to maintain its shielding effectiveness and prevent its contents from being dispersed in spite of the bumps, drops, vibrations, temperature extremes, pressure reductions, and even dousing with water that might take place in "normal" commercial shipping. For more specifics on Type A packaging, see pp. 19–20.

Appendix II Measuring Radiation

A **curie** is a unit of measurement that tells precisely how many individual atoms are giving off radiation within a given sample of radioactive material at any particular time.

One curie is the amount of radioactivity in which 37 billion atoms undergo some sort of nuclear transformation in 1 second. The radiating atoms may be concentrated in a pinhead or spread through a huge volume of material. Even though some radionuclides "decay" through radiation into radioactive "daughter products" (which prolong the radioactivity in a sample by going through radioactive decay themselves), the number of curies in any material tends to decrease as time passes.

This measurement doesn't indicate the type of radiation given off, and it doesn't show how concentrated the radiation field is unless the number of curies is related to a specific volume. Nevertheless, it is a valuable term in dealing with the transportation of radioactive material because the volumes involved are usually relatively small and the type of material being transported (and thus the nature of the radiation) is almost always known.

A **roentgen** is a unit of radiation that—technically speaking—applies only to X rays and another penetrating form of radiation called gamma rays. It measures the amount of such radiation that a person or object has *absorbed*. Just as the number of curies doesn't show *concentration* directly, so the number of roentgens involved does not reveal by itself the *intensity* of radiation. For example, 1 roentgen could be absorbed by someone who was exposed to X rays of a certain strength and at a certain distance for 1 minute, while it might take a whole year of exposure to a much *weaker* radiation field to absorb the same "dose" (a single roentgen). The only reason for mentioning this term at all is that it forms part of the definition for the third unit—the most important of all.

A **rem** is a shorthand symbol for the phrase "*r*oentgen *e*quivalent, *m*an". It is the unit of measurement that starts to put things together in a way that bears directly on health and safety. Like a curie it applies to *any* type of radiation or *any*

type of radioactive material. But rem is a gauge of biological effect on a human being; 1 rem represents the amount of *any* kind of radiation (strong or weak, close or distant) that has the same biological impact as 1 roentgen of gamma rays under certain specified conditions. As you might imagine, a measurement of rems can't be read directly from the dial of an instrument; it must be calculated.

Rems can be an ambiguous measurement too, because they may be calculated for direct radiation only (the so-called "shine" from radioactive material) or they might be calculated to include longer-term and indirect effects as well (such as the "dose commitment") that could result from absorbing radioactive particles that reconcentrated in a human food chain and eventually lodged in a part of the human body where they might remain for some time before being flushed out. Furthermore, some parts of the body (such as the eyes and the reproductive organs) are more sensitive to nuclear radiation than the body as a whole, so very refined computations may specify whether or not the full radiation dose would reach these particular areas.

In practice, most nuclear shipments involve very small amounts of radioactive isotopes. The quantities of radioactivity and radiation concerned in transportation are thus often much smaller than those expressed by curie, roentgen, and rem. Because these are all metric forms of measurement, it is easy and convenient to speak in terms of units only one-thousandth as great simply by tacking on the prefix "milli". Thus, a millicurie is 0.001 curie—one-thousandth of a curie. The same technique applies to milliroentgen and millirem. The abbreviations are as follows: Curie is Ci; millicurie is mCi; roentgen is r; and milliroentgen is mr. Rem, of course, is an abbreviation in itself, and millirem is mrem.

A relatively small number of shipments involve *very* large amounts of radioactivity, on the other hand. For instance, these would include bundles of nuclear fuel that have spent several years in a power reactor and are now headed for a reprocessing plant where the usable fuel material they contain can be separated from the nuclear waste. It is always possible to use the metric terms kilocurie and megacurie

(which equal 1000 and 1,000,000 curies respectively). But official reports often express larger numbers in another sort of shorthand, and this different form should also be understood by the nontechnical citizen who hopes to grasp the gist of what is being reported. Instead of writing 1000, an engineer or scientist will generally express this quantity as 10^3. Actually, this means 10 x 10 x 10 (which happens to be 1000); but there is another key to its meaning that most laymen find easier to remember. 10^x (you can substitute *any* number in the superscript) always equals 1 followed by *that* number of zeroes. In other words, $10^3 = 1000$, $10^4 = 10{,}000$, and $10^6 = 1{,}000{,}000$.

The same variety of shorthand is also used for very *small* numbers, except that then the superscripts are "minus numbers" (10^{-1}, 10^{-3}, etc.). These indicate fractions—in each case, a 1 *over* a 1 followed by the number indicated. Thus, 10^{-1} means the same thing as $1/10$ and $10^{-3} = 1/1000$.

Bibliography

Radioactive Materials Transportation Manual, Tri-State Motor Transit Company, P. O. Box 113, Joplin, Missouri 64801, 46 pp., 1974, single copies free.

Regulations of the U. S. Nuclear Regulatory Commission, Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions", Nuclear Regulatory Commission, Washington, D. C. 20555, 11 pp., single copies free.

Shipments of Nuclear Fuel and Waste . . . Are They Really Safe? (WASH-1339), U. S. Atomic Energy Commission, August 1974, 11 pp. Single copies are available free from the USERDA-TIC, P. O. Box 62, Oak Ridge, Tennessee 37830.

Transportation of Nuclear Fuel Material in the United States, Nuclear Assurance Corporation, 24 Executive Park West, Atlanta, Georgia 30329, 1970, 112 pp., $20.00.

The following documents are available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402:

Environmental Survey of the Uranium Fuel Cycle (WASH-1248), U. S. Atomic Energy Commission, April 1974, 250 pp., $2.85.

Everything You Always Wanted to Know About Shipping High-Level Nuclear Wastes (WASH-1264), U. S. Atomic Energy Commission, August 1974, 49 pp., $0.65.

Radiological Emergency Procedures for the Non-Specialist, U. S. Atomic Energy Commission, January 1969, 35 pp., $0.50.

Regulations of the U. S. Department of Transportation, Title 49, Code of Federal Regulations, Parts 170-189, "Hazardous Materials Regulations", October 1974, $7.20.

The following documents are available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161:

Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants (WASH-1238), U. S. Atomic Energy Commission, December 1972, 126 pp., $5.75.

Proceedings of the Conference on the Transportation of Radioactive Material Sponsored by the University of Virginia (PB 189-506), Charlottesville, Virginia, October 26–28, 1969, 159 pp., $6.25.

Proceedings of the Fourth International Symposium on Packaging and Transportation of Radioactive Materials (CONF-740901), September 22–27, 1974, Miami Beach, Florida, 1195 pp., $31.80 (paperback); $4.35 (microfiche).

Proceedings of Southern Governors Conference on Transportation of Nuclear Spent Fuel (CONF-700207), Atlanta, Georgia, February 5–6, 1970, 167 pp., $3.00.

Motion Pictures

The following are available for loan without charge from the USERDA–TIC Film Library, P. O. Box 62, Oak Ridge, Tennessee 37830.

On the Move, 28 minutes, color, 1974. Designed for the general public, this film shows the variety of nuclear shipments being made and explains briefly the steps taken to protect public health and safety.

The Wooden Overcoat, 14 minutes, color, 1965. A more technical and specialized film than the one above, this deals with a wooden "outer shell" designed to give additional protection to metal shipping containers for radioactive materials. Scenes of actual testing are typical of the rugged scrutiny given to design claims about survivability under accident conditions.

PHOTO CREDITS

Page	
Page facing page 1	Oak Ridge National Laboratory
9	Baltimore Gas and Electric Company
11	Nuclear Fuel Services, Inc.
14	7A, U. S. Vanadium Company; 7E, Baltimore Gas and Electric Company; 7F, General Electric Company.
20, 21, 23, and 26	Oak Ridge National Laboratory
35 and 46	Union Carbide Corporation

☆U.S. GOVERNMENT PRINTING OFFICE: 1975 - 641-240/4

A word about ERDA . . . .

The mission of the Energy Research & Development Administration (ERDA) is to develop all energy sources, to make the Nation basically self-sufficient in energy, and to protect public health and welfare and the environment. ERDA programs are divided into six major categories:

- CONSERVATION OF ENERGY—More efficient use of both existing and new sources of energy in industry, transportation, heating and cooling of buildings, and the generation of electricity, together with more efficient transmission of energy.
- FOSSIL ENERGY—Expansion of coal production and the development of technologies for converting coal to synthetic gas and liquid fuels, improvement of oil drilling methods, and development of techniques for converting shale deposits to usable oil.
- SOLAR, GEOTHERMAL, AND ADVANCED ENERGY SYSTEMS—Application of solar energy to heat and cool buildings and development of solar-electric power, conversion of underground heat sources for electricity and industrial heat, and development of hydrogen fusion for generating electricity.
- ENVIRONMENT AND SAFETY—Investigation of health, safety, and environmental effects of energy technologies, and research on managing wastes from energy production.
- NUCLEAR ENERGY—Expansion of medical, industrial and research applications; advancement of reactor technologies for generating electricity, especially the breeder concept; and production of nuclear materials for civilian needs.
- NATIONAL SECURITY—Development, production, and testing of nuclear weapons and attention to such related issues as safeguards and international security matters.

ERDA programs are carried out by contract and cooperation with industry, university communities, and other government agencies. For more information, write to USERDA-Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

Energy Research and Development Administration
Office of Public Affairs
Washington, D.C. 20545